Enhancing LSST with New Spectroscopy

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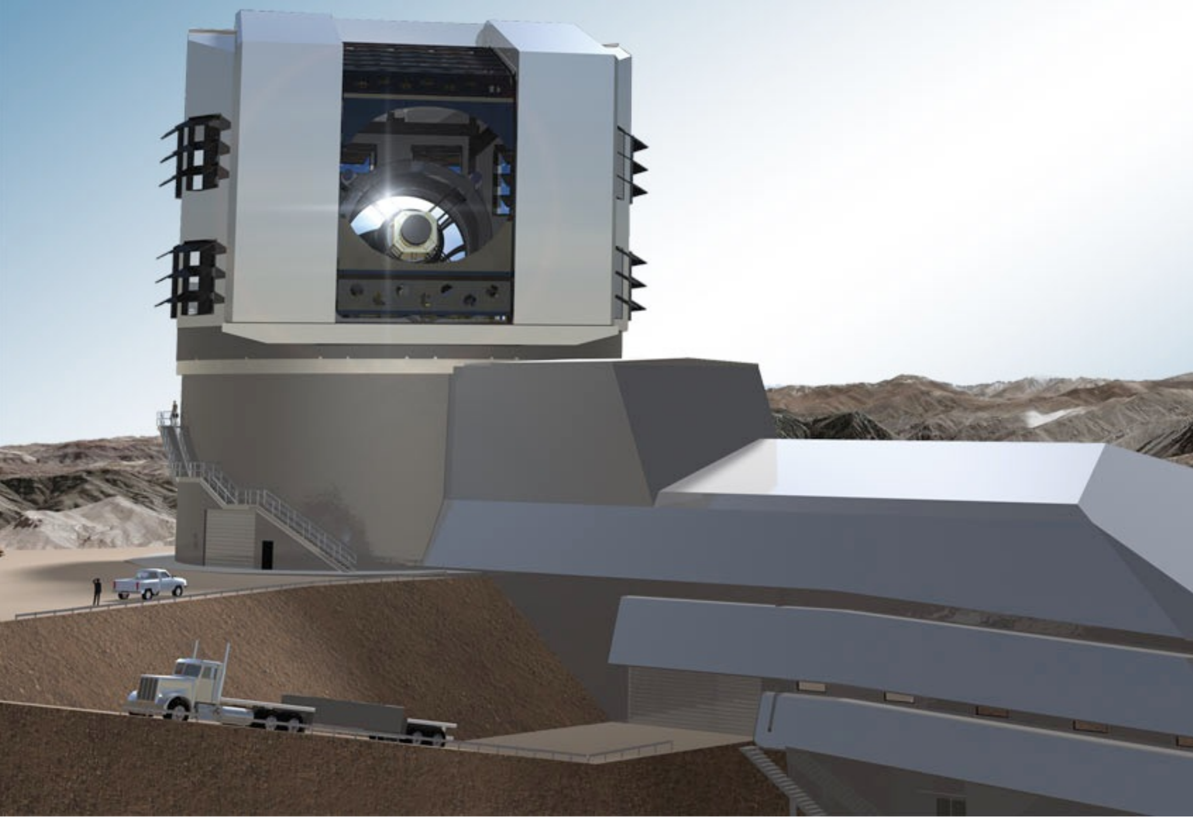


- **See Snowmass white papers on *Cross-Correlations* and *Spectroscopic Needs for Imaging Dark Energy Experiments* for more details!**

Outline

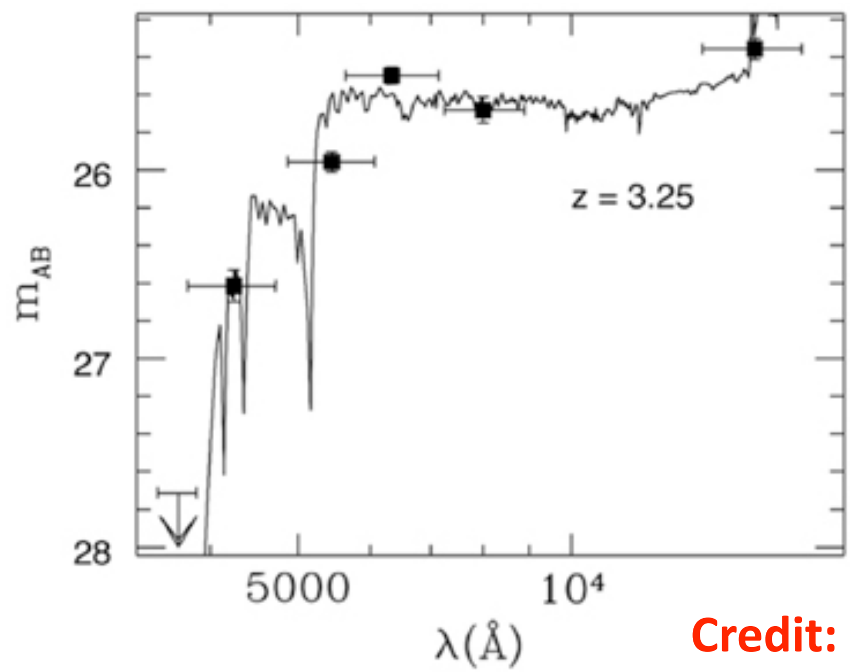
- **Improving the LSST Figure of Merit: Spectroscopy for training photometric redshifts**
- **Mitigating LSST systematics: DESI-South to improve photo-z calibration via cross-correlations**
- **Another role for DESI: Supernova host redshifts**

- **See Snowmass white papers on *Cross-Correlations* and *Spectroscopic Needs for Imaging Dark Energy Experiments* (http://arxiv.org/abs/1309.5384, 1309.5388) for much more!**

Spectroscopy provides ideal redshift measurements – but is infeasible for large samples

- At LSST "gold sample" (i<25.3) depths, ~180 hours on a 10m telescope to determine a redshift (70% of time) spectroscopically
- With a next-generation, 5000 fiber spectrograph on a 10m telescope, still >50,000 telescope-years to measure redshifts for LSST "gold" weak lensing sample (4 billion galaxies)!

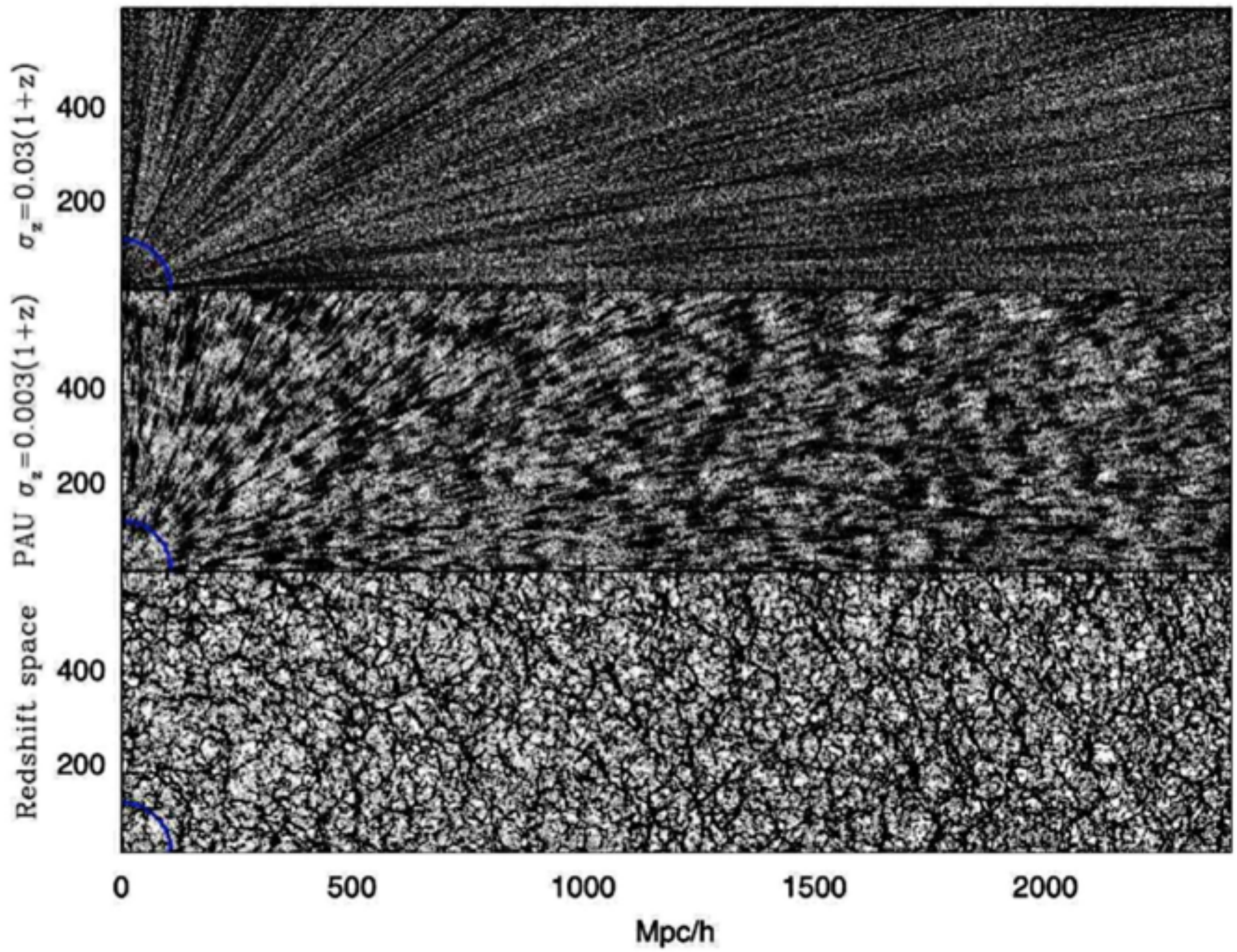
- Alternative: use broad spectral features to determine z : a photometric redshift
- Advantage: high multiplexing
- Disadvantages: lower precision, calibration uncertainties



Credit: ESO

Two spectroscopic needs for photo-z work: training and calibration

- Better training of algorithms using objects with spectroscopic redshift measurements shrinks photo-z errors and improves DE constraints, esp. for BAO and clusters



Benitez et al. 2009

  - Training datasets will contribute to calibration of photo-z's. ~Perfect training sets can solve calibration needs.

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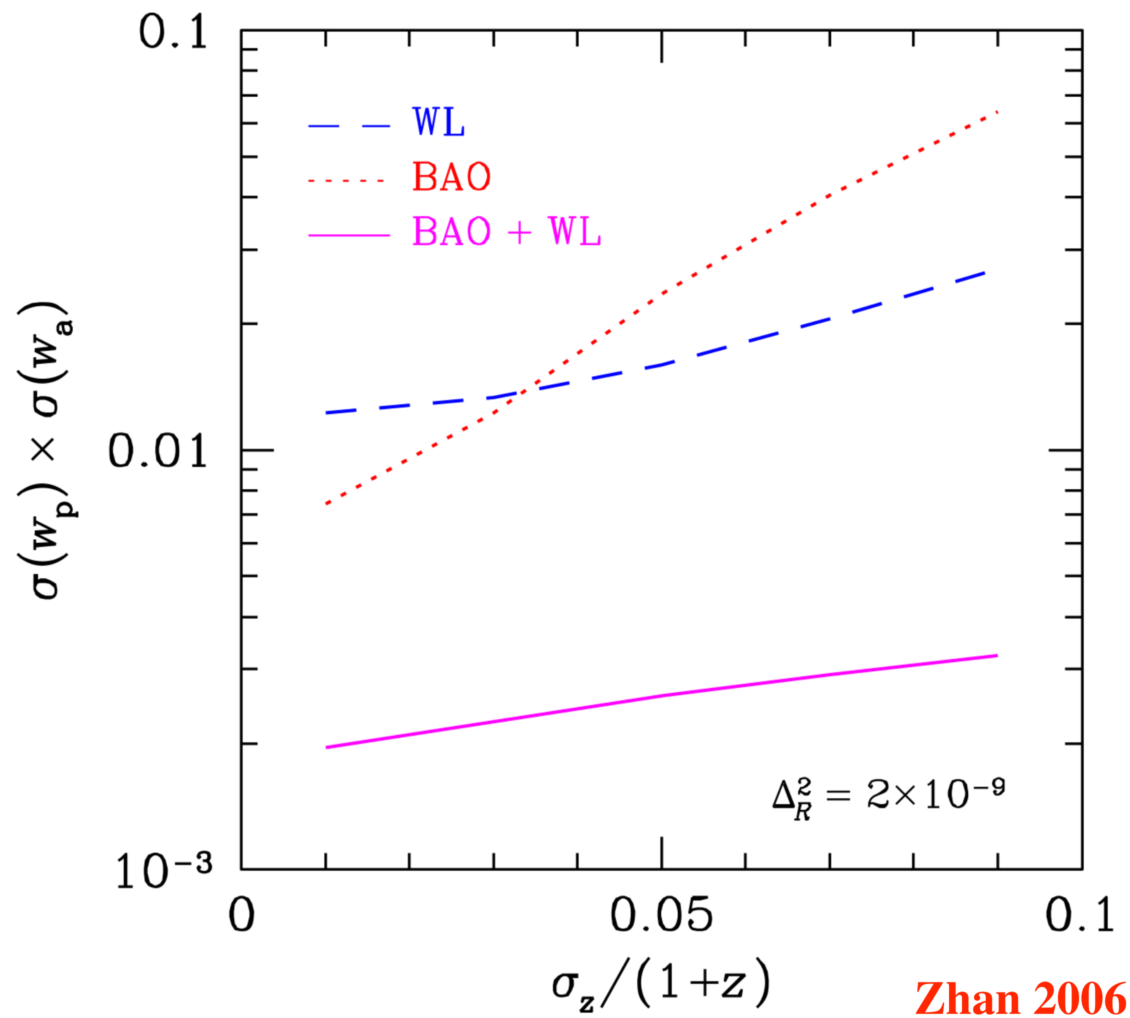
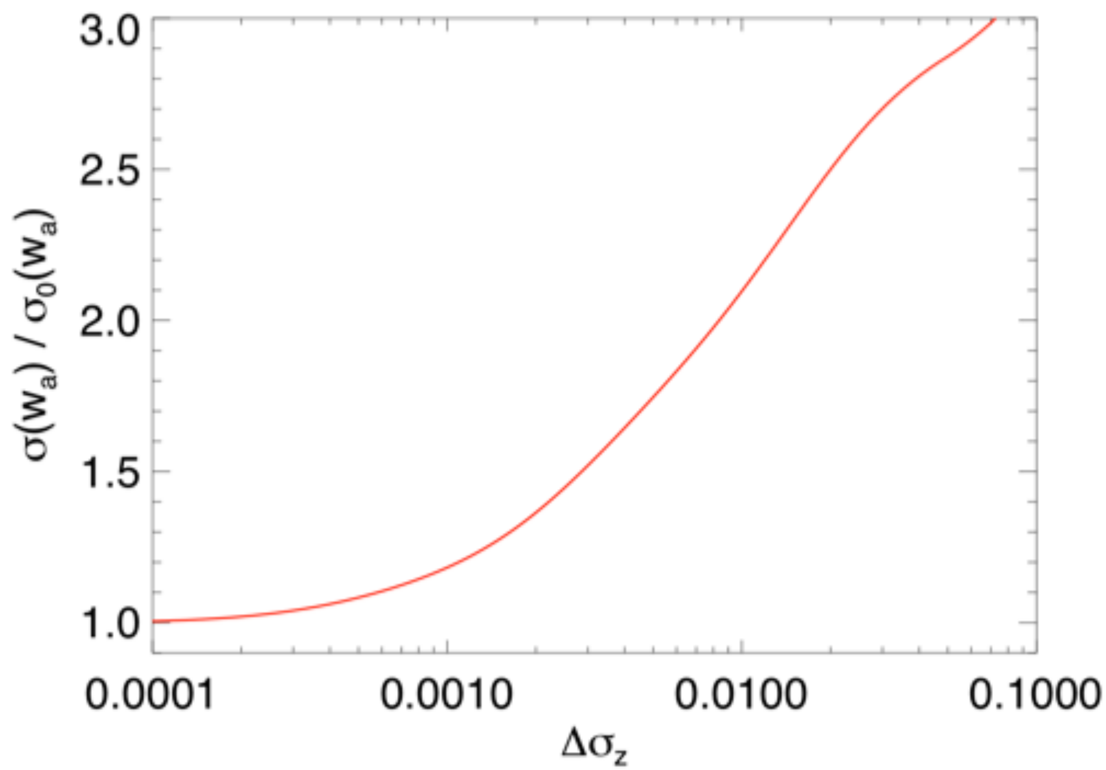


Zhan 2006

  - Training datasets will contribute to calibration of photo-z's. ~Perfect training sets can solve calibration needs.

Two spectroscopic needs for photo-z work: training and calibration

- For weak lensing and supernovae, individual-object photo-*z*'s do not need high precision, but the calibration must be accurate - i.e., bias and errors need to be extremely well-understood



Newman et al. 2013

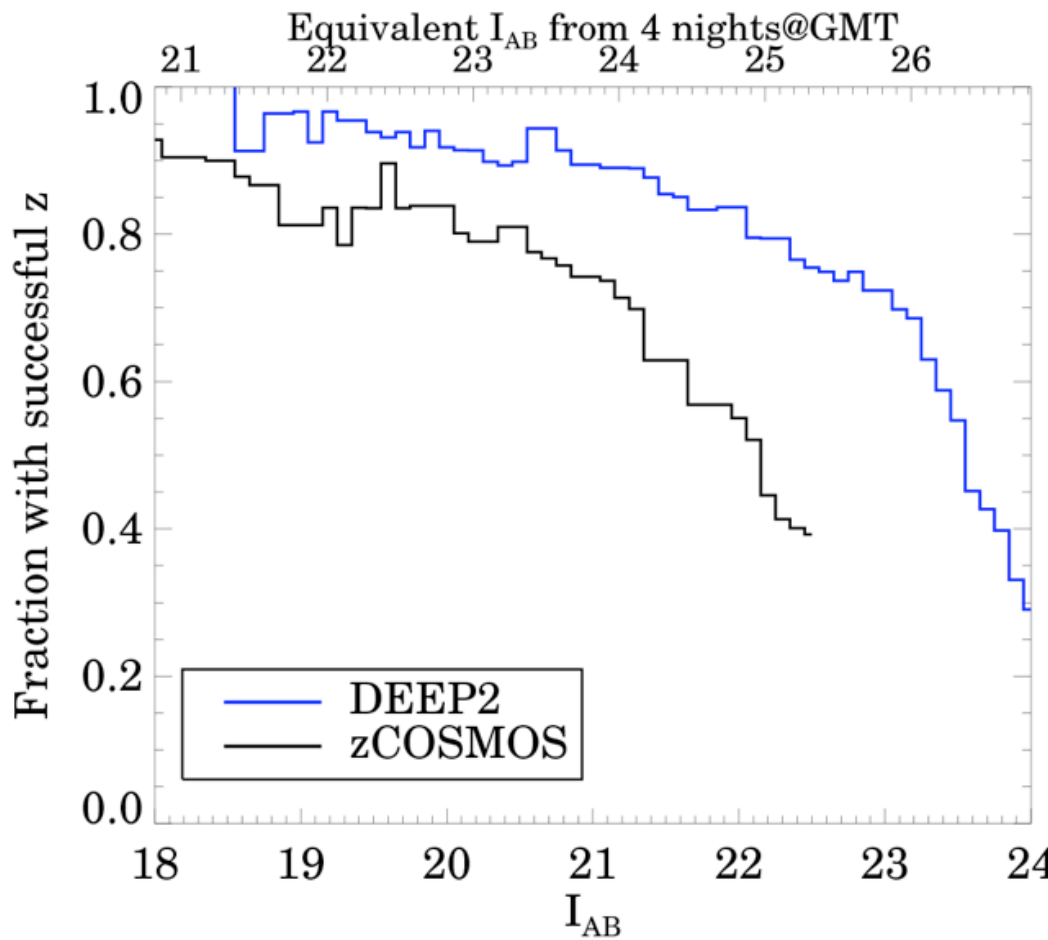
  – *uncertainty in* bias, $\sigma(\delta_z) = \sigma(<z_p - z_s>)$, and in scatter, $\sigma(\sigma_z) = \sigma(RMS(z_p - z_s))$, must both be <~0.002(1+*z*) for Stage IV surveys

Major issue: incompleteness in training/calibration datasets

- In current deep redshift surveys (to i~22.5/R~24), 25-60% of targets fail to yield secure (>95% confidence) redshifts

- Redshift success rate depends on galaxy properties - losses are systematic, not random

- Estimated need 99-99.9% completeness to prevent systematic errors in calibration from missed populations; without that, spectra are useful for training but not calibration



Data from DEEP2 (Newman et al. 2013) and zCOSMOS (Lilly et al. 2009)

What qualities do we desire in training spectroscopy?

- Sensitive spectroscopy of ~30,000 faint objects (to i=25.3 for LSST)

  - Needs a combination of large aperture and long exposure times

- High multiplexing

  - Required to get large numbers of spectra

- Coverage of full ground-based spectral window

  - Ideally, from below 4000 Å to ~1.5μm

- Significant resolution ($R=\lambda/\Delta\lambda$>~4000) at red end

  - Allows secure redshifts from [OII] 3727 Å line at z>1

- Field diameters > ~20 arcmin

  - Need to span several correlation lengths for accurate clustering

- Many fields, >~15

  - To mitigate sample/cosmic variance)

Summary of (some!) potential instruments

Telescope / Instrument	Collecting Area (m^2)	Field area ($arcmin^2$)	Multiplex	Limiting factor
Keck / DEIMOS	76	54.25	150	Multiplexing
VLT / MOONS	58	500	500	Multiplexing
Subaru / PFS (≈MSE)	53	4800	2400	# of fields
Mayall 4m / DESI	11.4	25500	5000	# of fields
WHT / WEAVE (≈4MOST)	13	11300	1000	Multiplexing
GMT/MANIFEST+GMACS	368	314	420-760	Multiplexing
TMT / WFOS	655	40	100	Multiplexing
E-ELT / MOSAIC	978	39-46	160-240	Multiplexing

Table 2-1. *Characteristics of current and anticipated telescope/instrument combinations relevant for obtaining photometric redshift training samples. Assuming that we wish for a survey of ~15 fields of at least 0.09 deg² each yielding a total of at least 30,000 spectra, we also list what the limiting factor that will determine total observation time is for each combination: the multiplexing (number of spectra observed simultaneously); the total number of fields to be surveyed; or the field of view of the selected instrument. For GMT/MANIFEST+GMACS and VLT/OPTIMOS, a number of design decisions have not yet been finalized, so a range based on scenarios currently being considered is given.*

Time required for each instrument

Telescope / Instrument	Total time(y), DES / 75% complete	Total time(y), LSST / 75% complete	Total time(y), DES / 90% complete	Total time(y), LSST / 90% complete
Keck / DEIMOS	0.51	10.22	3.19	63.89
VLT / MOONS	0.20	4.00	1.25	25.03
Subaru / PFS (≈MSE)	0.05	1.10	0.34	6.87
Mayall 4m / DESI	0.26	5.11	1.60	31.95
WHT / WEAVE (≈4MOST)	0.45	8.96	2.80	56.03
GMT/MANIFEST+GMACS	0.02 - 0.04	0.42 - 0.75	0.13 - 0.24	2.60 - 4.71
TMT / WFOS	0.09	1.78	0.56	11.12
E-ELT / MOSAIC	0.02 - 0.04	0.50 - 0.74	0.16 – 0.23	3.10 - 4.65

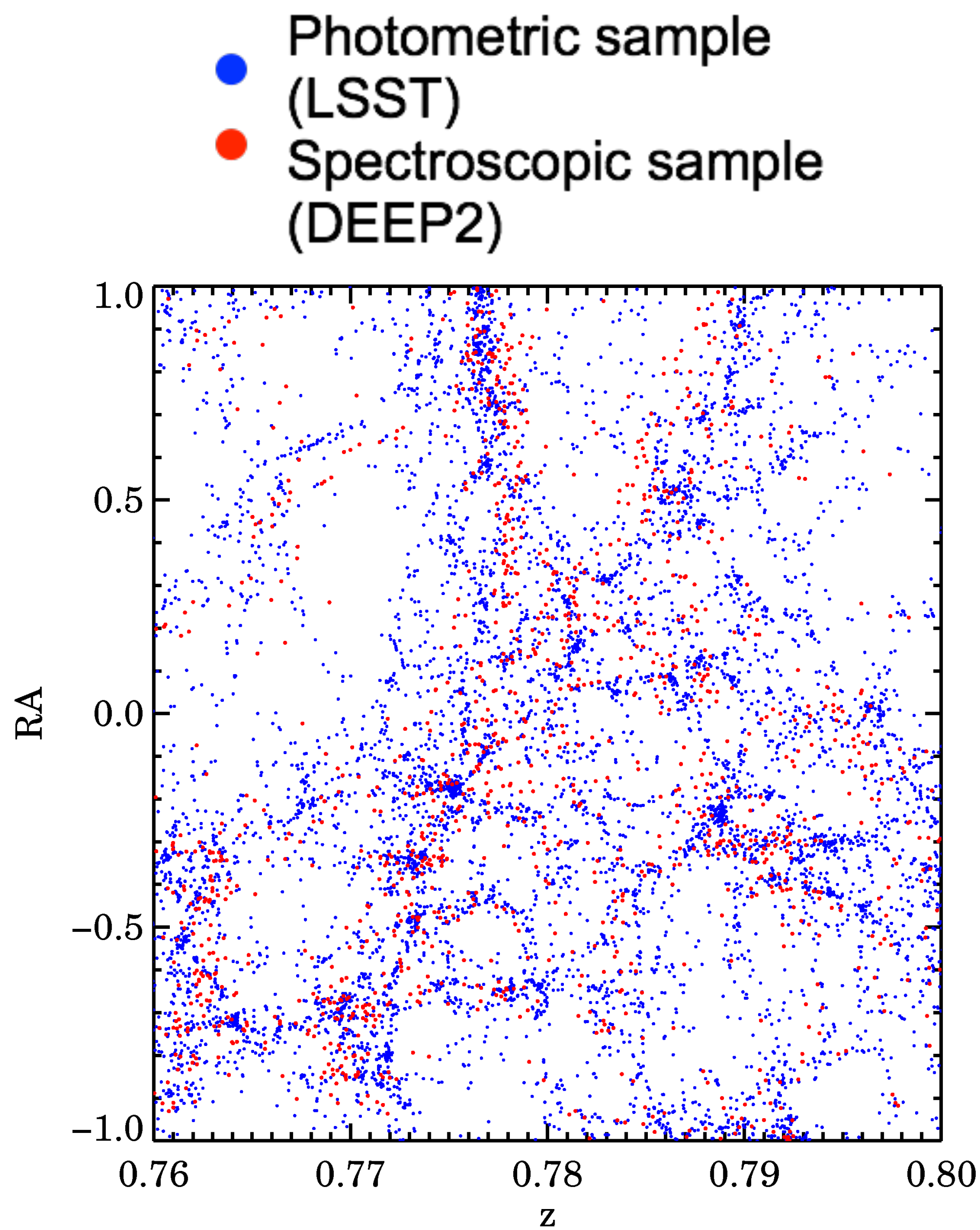
Table 2-2. *Estimates of required total survey time for a variety of current and anticipated telescope/instrument combinations relevant for obtaining photometric redshift training samples. Calculations assume that we wish for a survey of ~15 fields of at least 0.09 deg^2 each, yielding a total of at least 30,000 spectra. Survey time depends on both the desired depth (i=23.7 for DES, i=25.3 for LSST) and completeness (75% and 90% are considered here). Exposure times are estimated by requiring equivalent signal-to-noise to 1-hour Keck/DEIMOS spectroscopy at i~22.5. GMT / MANIFEST + GMACS estimates assume that the full optical window may be covered simultaneously at sufficiently high spectral resolution; in some design scenarios currently being considered, that would not be the case, increasing required time accordingly.*

Estimated time and cost requirements for training sets

- **LSST / 75% complete:**
  - ➡ 1.1 - 5.1 years (c. 2018), 0.42+ years (c. 2022+)
  - ➡Approximate cost (@Subaru/PFS or DESI): $20-25M
- **LSST / 90% complete:**
  - ➡ 6.9 - 32 years (c. 2018), 2.6+ years (c. 2022+)
  - ➡Approximate cost (@Subaru/PFS): $125M
- **Large overlap in science and strategy with galaxy evolution surveys; cost-sharing is a likely possibility**

Cross-correlation methods: exploiting redshift information from galaxy clustering

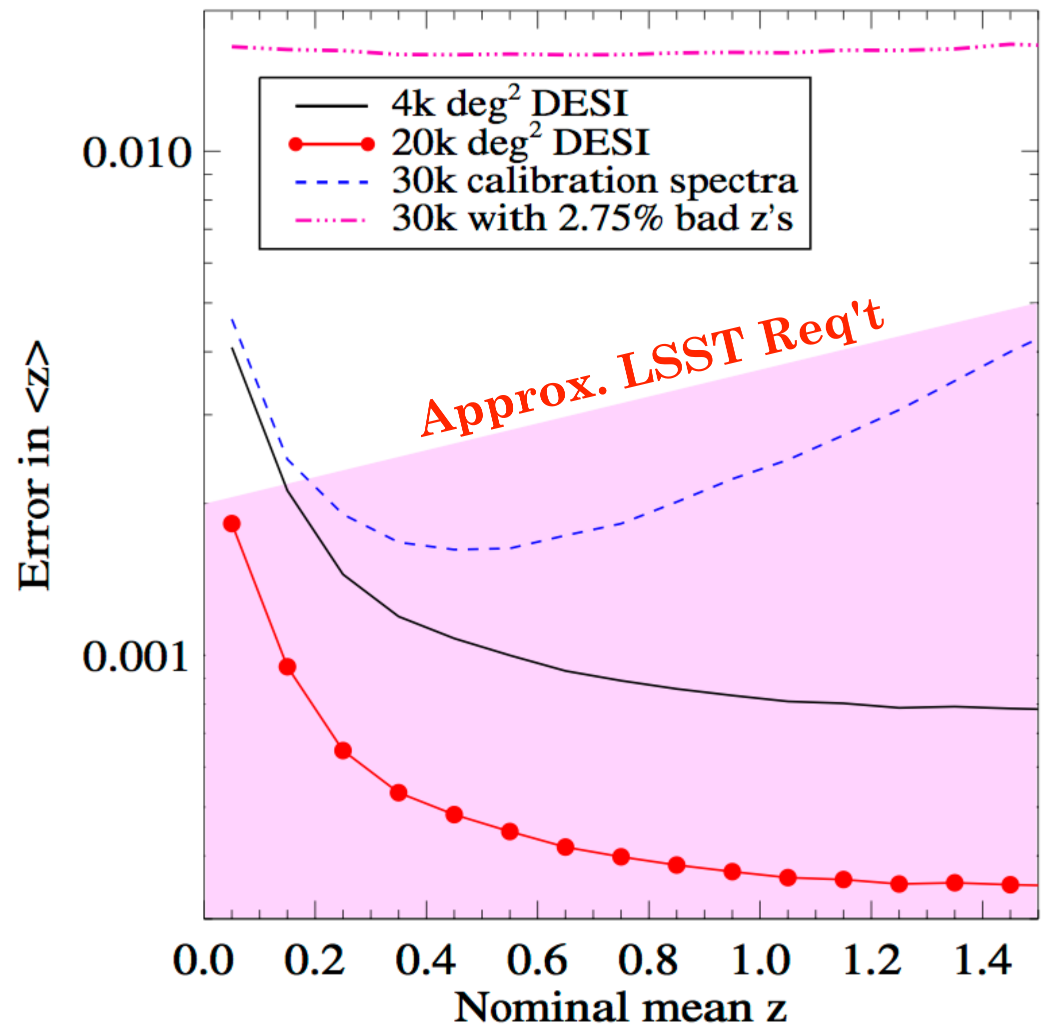
- **Galaxies of all types cluster together: trace same dark matter distribution**
- **Galaxies at significantly different redshifts do not cluster together**
- **From observed clustering of objects in one sample vs. another (as well as information from autocorrelations), can determine the fraction of objects in overlapping redshift range**
- **Do this as a function of spectroscopic *z* to recover *p(z)***



Spectroscopic requirements for cross-correlation methods

- Want large sets of redshifts over wide areas, spanning z range of photometric sample. Galaxy +QSO BAO surveys are great for this.

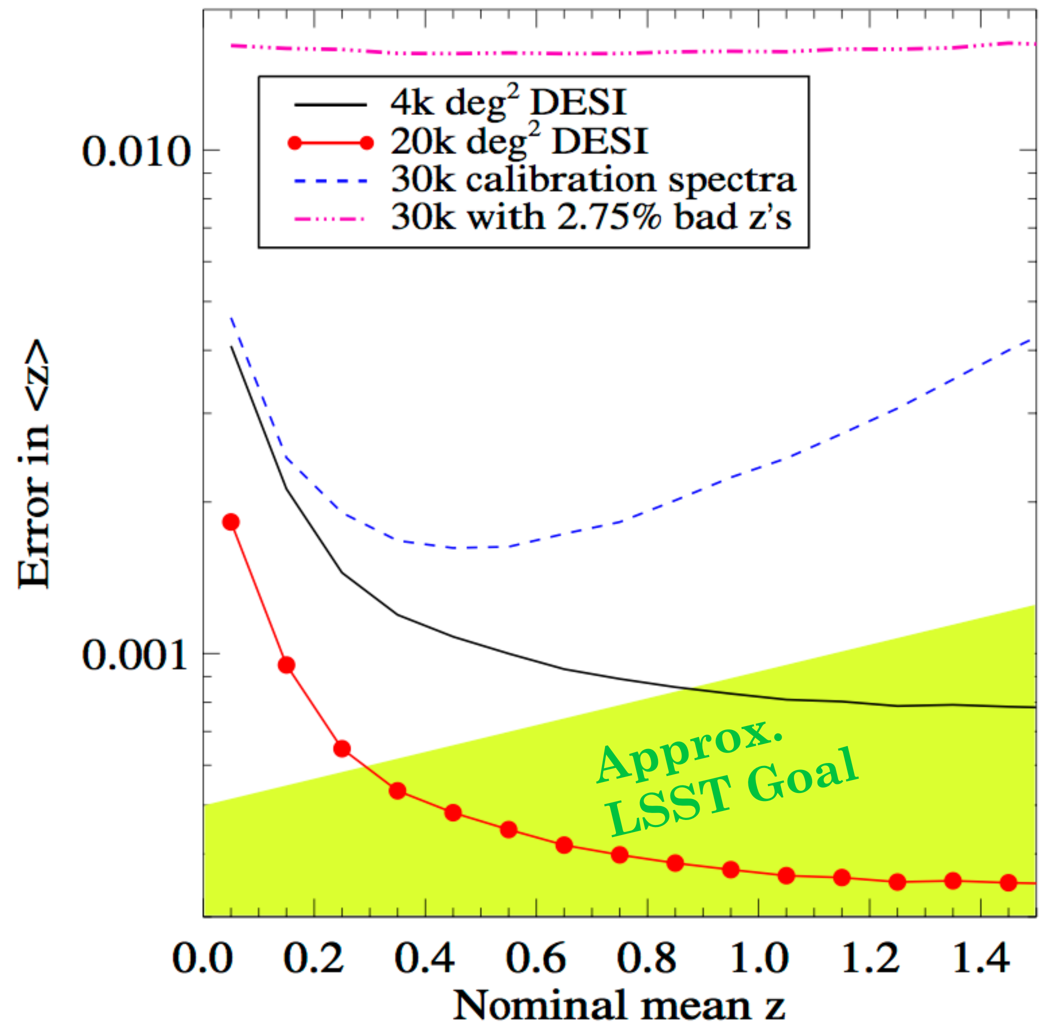
- Expected ~4000 deg^2 overlap between DESI and LSST yields better calibration than a 100% complete sample of 30k spectra with no false z's, as free byproduct of DESI



Snowmass White Paper: Spectroscopic Needs for Imaging DE Experiments

Spectroscopic requirements for cross-correlation methods

- Photo-z calibration will still be degrading LSST Figure of Merit in this scenario
- To reduce figure of merit degradation to <10%, requirements are more stringent
- Ideal case: move DESI to Blanco telescope after DESI survey; cover full LSST footprint with extended BAO survey
- Approximate total cost for survey: $30M-40M



Snowmass White Paper: Spectroscopic Needs for Imaging DE Experiments

Another application of DESI: supernova host redshifts

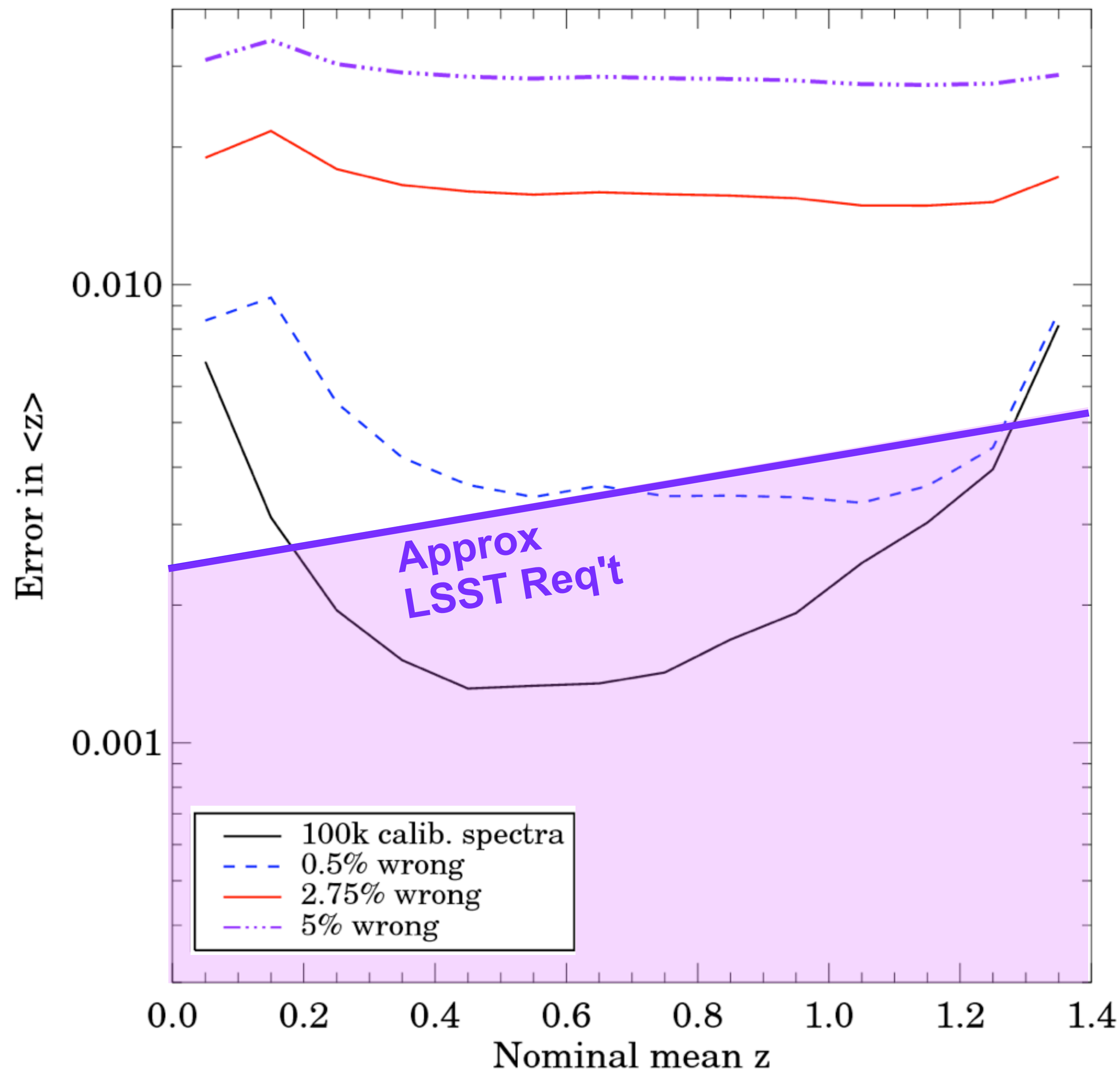
- The most useful LSST supernovae will be those found in 20-30 repeatedly-imaged 'deep drilling' fields
- >30,000 SNe Ia spread out over 300 square degrees found over 10 years
- Mapping from Keck/DEIMOS experience, 8 hours on DESI should yield redshifts for ~70% of hosts to r~24
  - ~60 nights total on DESI to get redshifts for ~70% of the supernovae - allows typing and cosmological analyses
- This would take >2000 nights with Keck/DEIMOS
- Less-valuable but much more numerous LSST-wide supernova hosts would have redshifts measured for free from DESI-south survey

Conclusions

- Photo-z's are critical for LSST; may be limiting systematic
- Minimum LSST photo-z training survey, ~75% complete:
  - 15 widely-separated pointings, ~30,000 spectra to *i* = 25.3, ~0.4 years on a 20-40m telescope (can do galaxy evolution science simultaneously)
- Cross-correlation methods can calibrate photometric redshifts even using incomplete samples of only bright galaxies & QSOs
- Extension of DESI to Southern hemisphere would provide ultimate cross-correlation calibration (plus improved constraints on DE from combined RSD/lensing analyses)
- DESI instrument could also be used to obtain host redshifts for LSST Type Ia supernovae, eliminating need for photo-z's for them
- See Snowmass white papers on *Cross-Correlations* and *Spectroscopic Needs for Imaging Dark Energy Experiments*, http://arxiv.org/abs/1309.5384, 1309.5388

Note: even for 100% complete samples, current false-z rates would compromise calibration accuracy

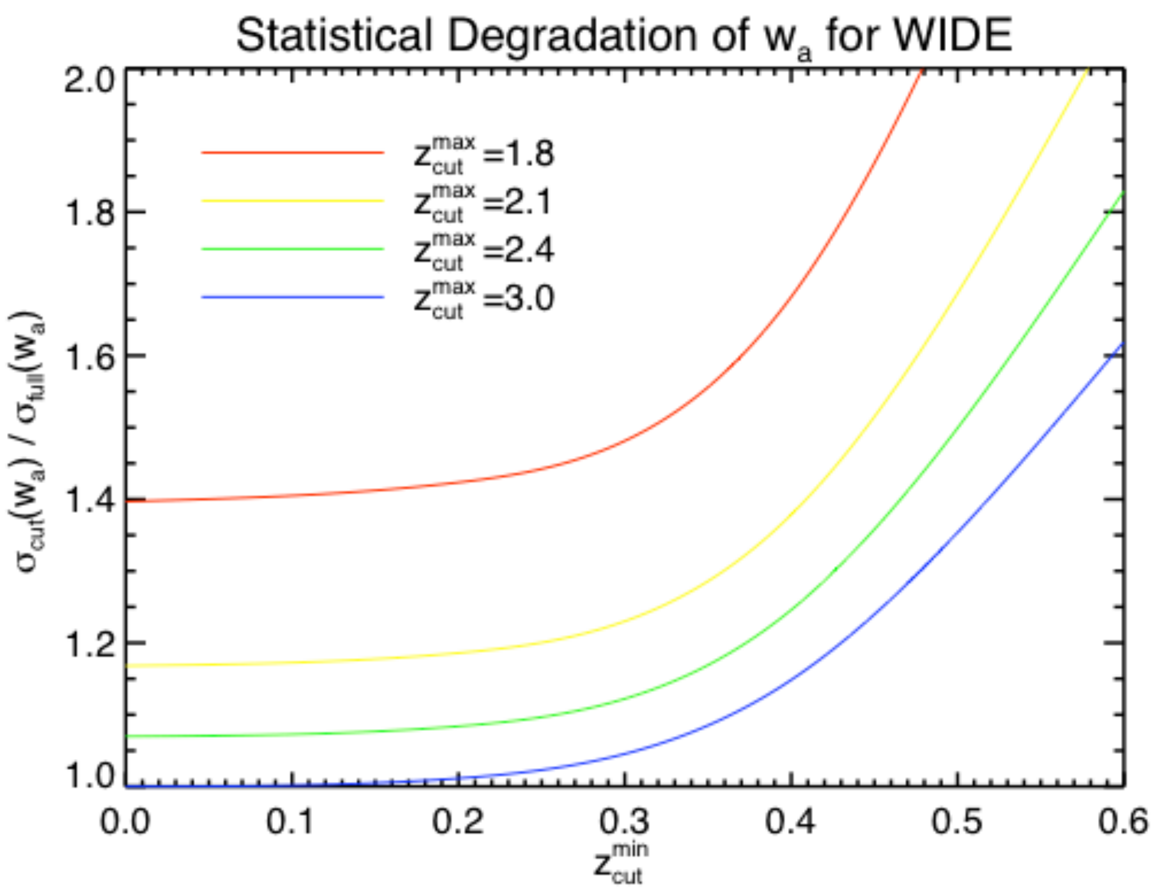
- **Only the highest-confidence redshifts should be useful for precision calibration: lowers spectroscopic completeness further when restrict to only the best**



Based on simulated redshift distributions for ANNz-defined DES bins in mock catalog from Huan Lin, UCL & U Chicago, provided by Jim Annis

Effect of rejecting objects at low redshift

- Cross-correlation calibration is most difficult at low z due to small volume/large sample/ cosmic variance
- Plots at right: weak lensing error degradation (vs. random errors only) as change minimum redshift (x axis) and maximum redshift (different-colored curves)
- Limiting to z<0.2 degrades DE FoM by a few percent



Hearin et al. 2010

Spectroscopic training set requirements

- Goal: make δ_z and $\sigma(\sigma_z)$ so small that systematics are subdominant
- Many estimates of training set requirements (Ma et al. 2006, Bernstein & Huterer 2009, Hearin et al. 2010, LSST Science Book, etc.)
- General consensus that roughly 20k-30k extremely faint galaxy spectra are required to characterize:
  - Typical z_{spec}-z_{phot} error distribution
  - Accurate catastrophic failure rates for all objects with $z_{phot} < 2.5$
  - Characterize all outlier islands in z_{spec}-z_{phot} plane via targeted campaign (core errors easier to determine)
- Those numbers of redshifts are achievable with GMT, if multiplexing is high enough

What qualities do we desire in our training sets?

- **Sensitive spectroscopy of faint objects (to i=23.7 for DES, 25.3 for LSST)**

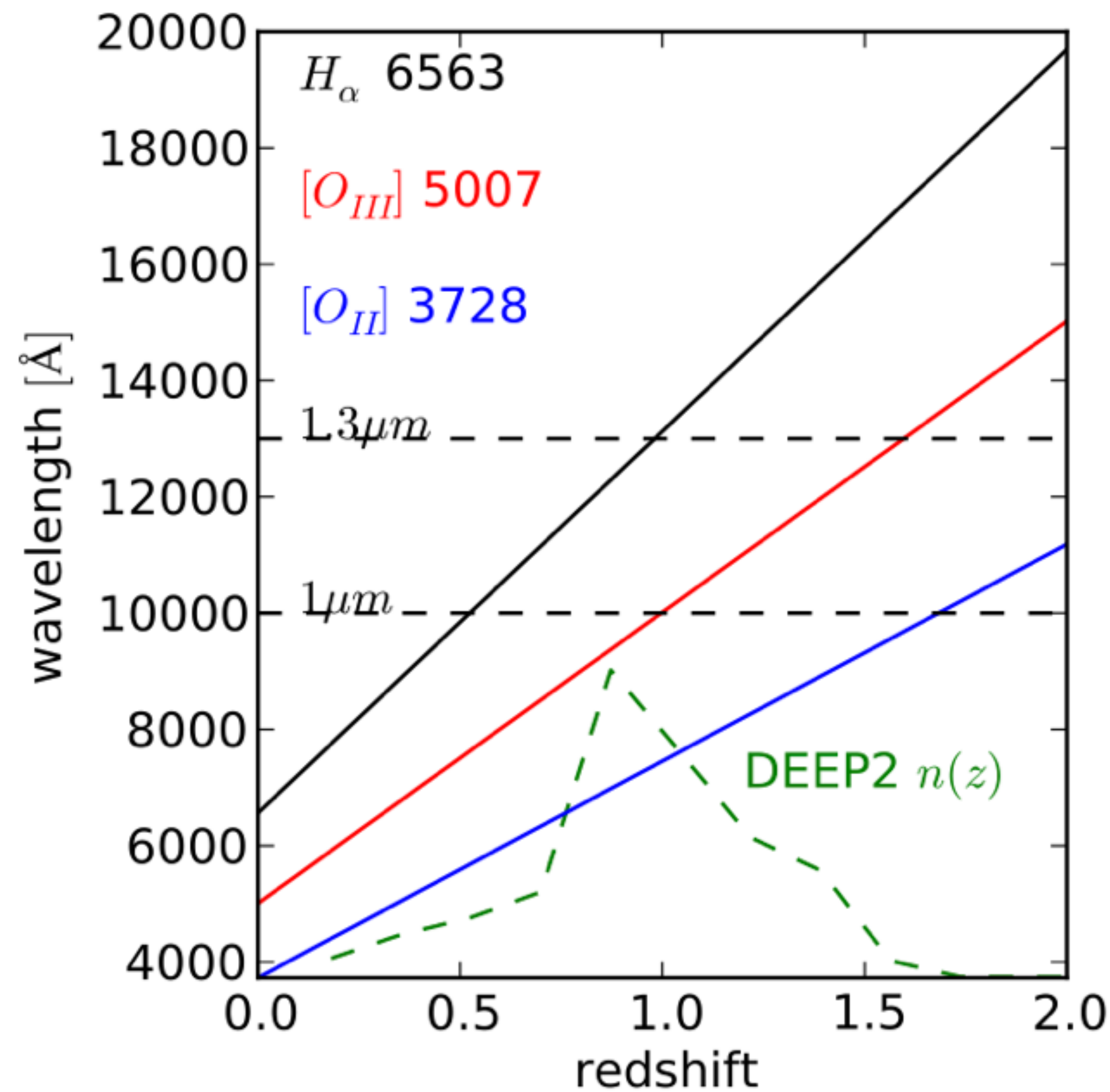
  - Need a combination of large aperture and long exposure times; >20 Keck-nights (=4 GMT-nights) equivalent per target, minimum

- **High multiplexing**

  - Obtaining large numbers of spectra is infeasible without it

What qualities do we desire in our training sets?

- **Coverage of full ground-based window**
  - **Ideally, from below 4000 Å to ~1.5μm**
    - **Require multiple features for secure redshift**

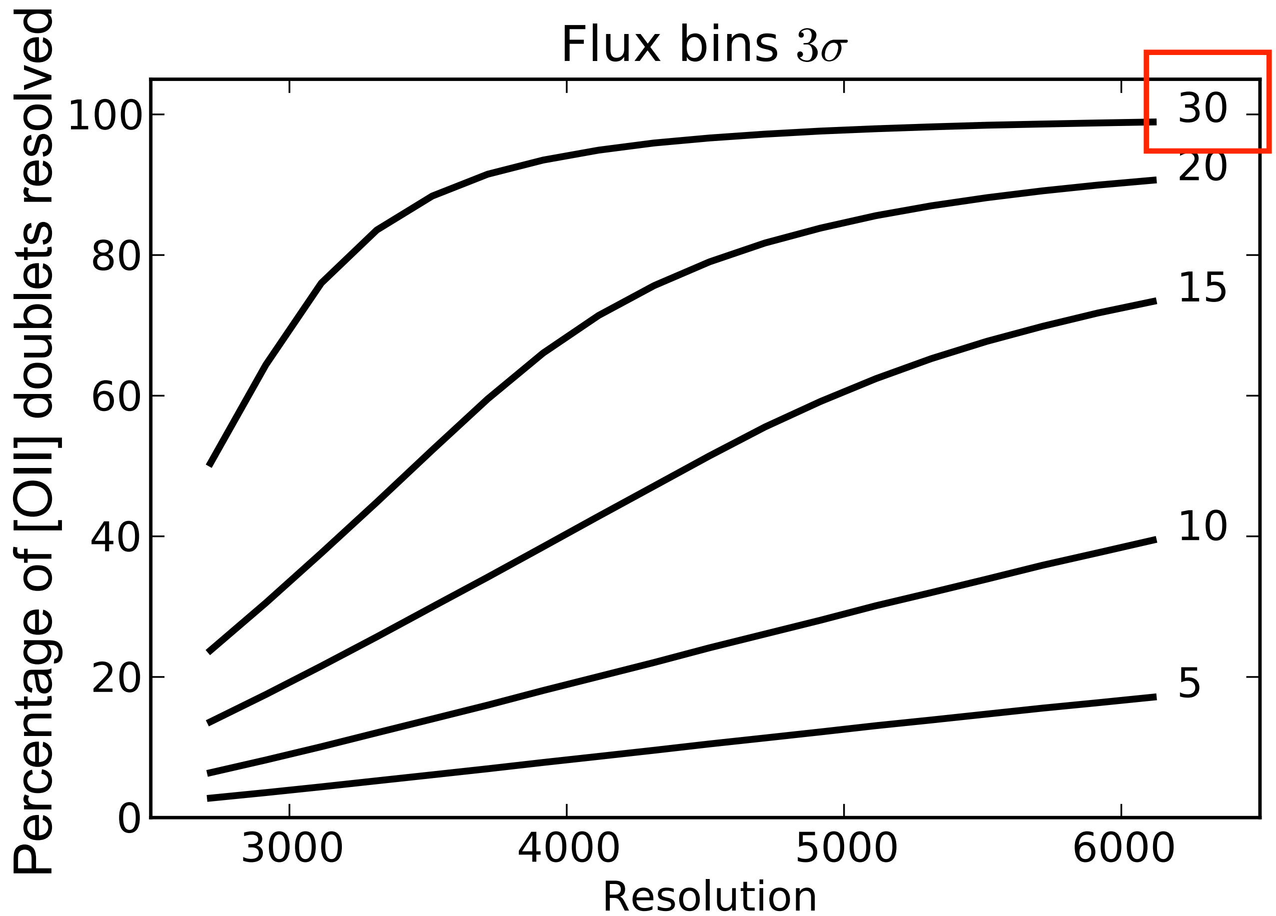


Comparat et al. 2013, submitted

What qualities do we desire in our training sets?

- **Significant resolution (R>~4000) at red end**

  - Allows redshifts from [OII] 3727 Å doublet alone, key at *z*>1



Comparat et al. 2013, submitted

What qualities do we desire in our training sets?

- **Field diameters > ~20 arcmin**

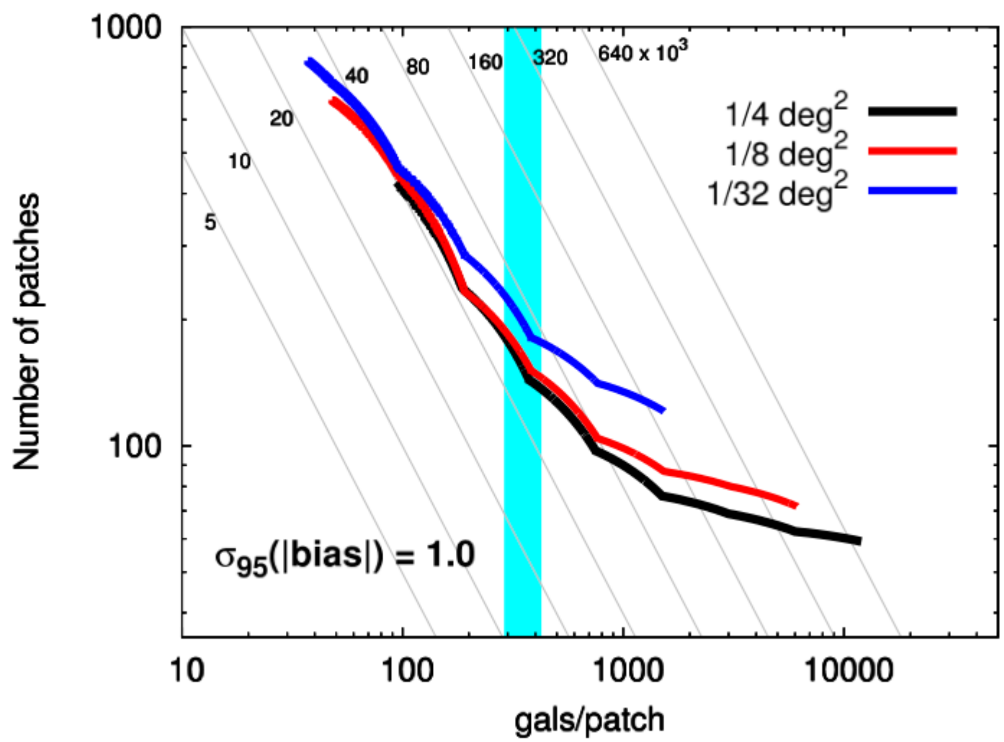
  - Need to span several correlation lengths for accurate clustering measurements (key for galaxy evolution science and cross-correlation techniques)

  - $r_0 \sim 5\ h^{-1}$ Mpc comoving corresponds to ~7.5 arcmin at z=1, 13 arcmin at z=0.5

- **Many fields**

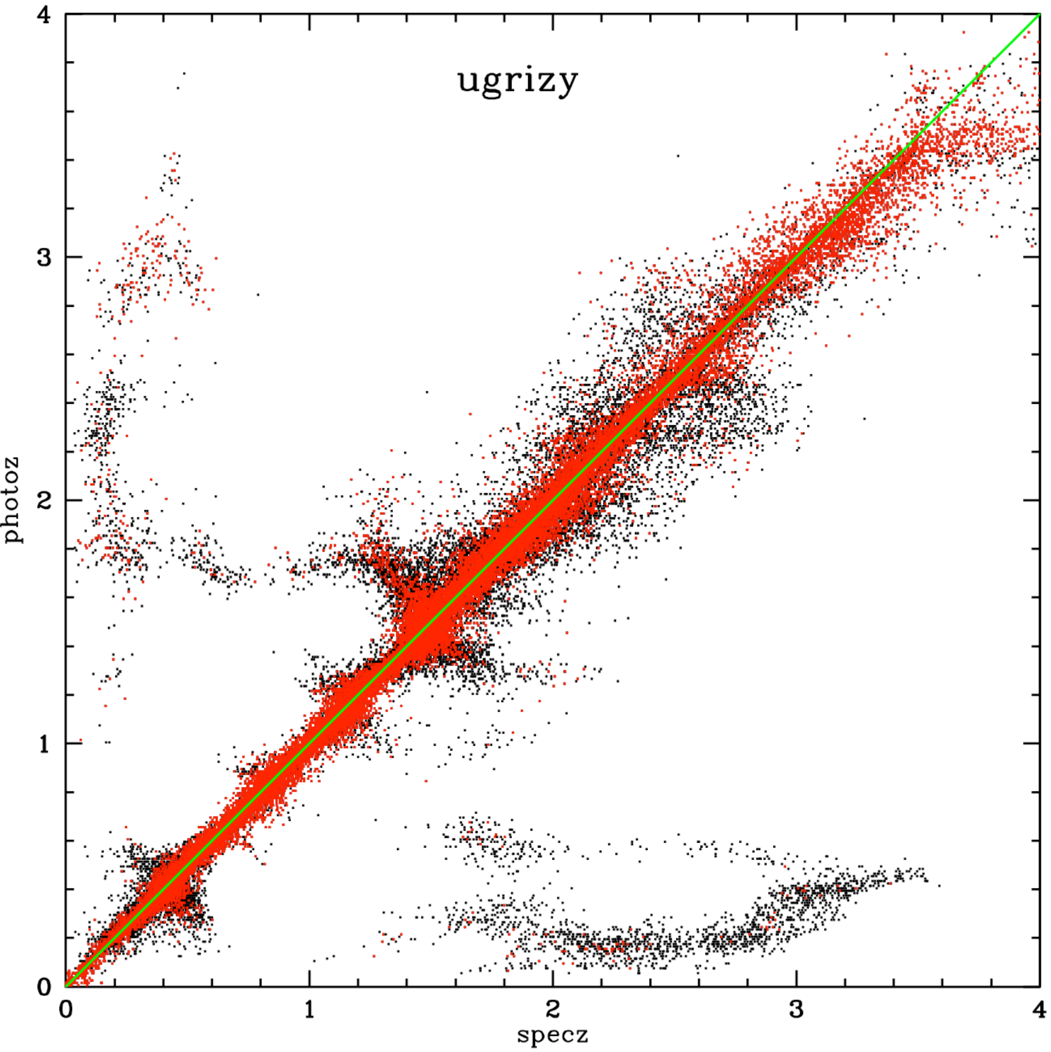
  - Minimizes impact of sample/ cosmic variance.

    - e.g., Cunha et al. (2012) estimate that 40-150 ~0.1 deg^2 fields are needed for DES for sample variance not to impact errors (unless we get clever)

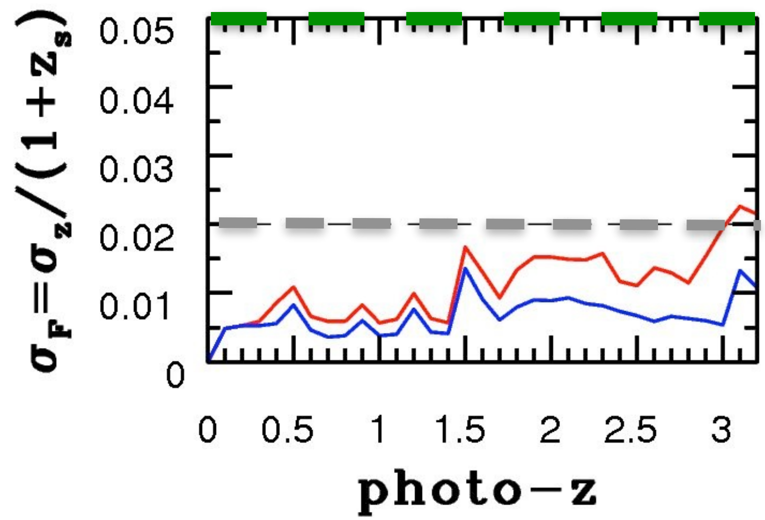


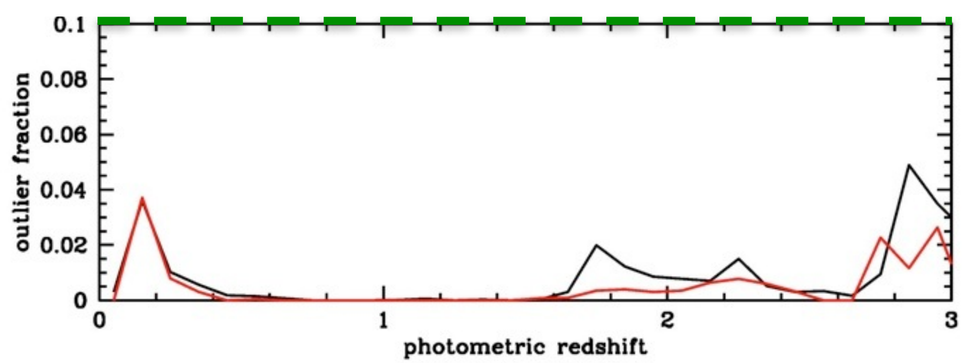
Cunha et al. 2012

Example: expected photo-z performance for LSST *ugrizy*



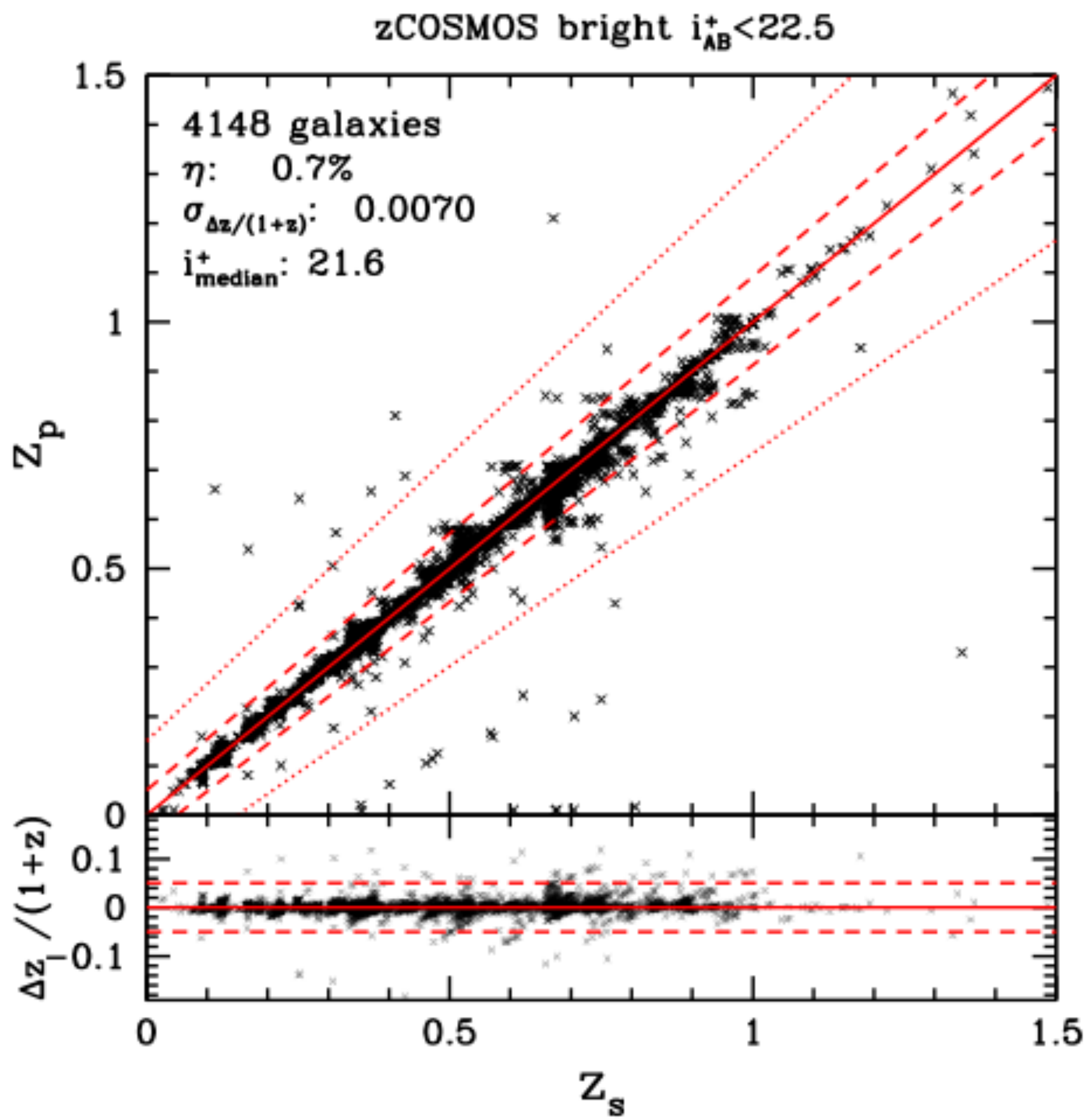
Green: Requirements on actual performance; grey: requirements on performance <u>with perfect template knowledge</u> (as in these sims)





Current state of the art photo-z's can achieve $\sigma_z < 0.01(1+z)$ for bright objects in best case

- **Deep imaging in 30 bands; ≈ very low-resolution spectrum**
- **Predicted errors become much worse, 0.04-0.14, past z~1.25 (degenerate redshift solutions when 4000Å break passes to infrared)**
- **MKIDS Giga-*z* performance would be ~comparable if works as planned**



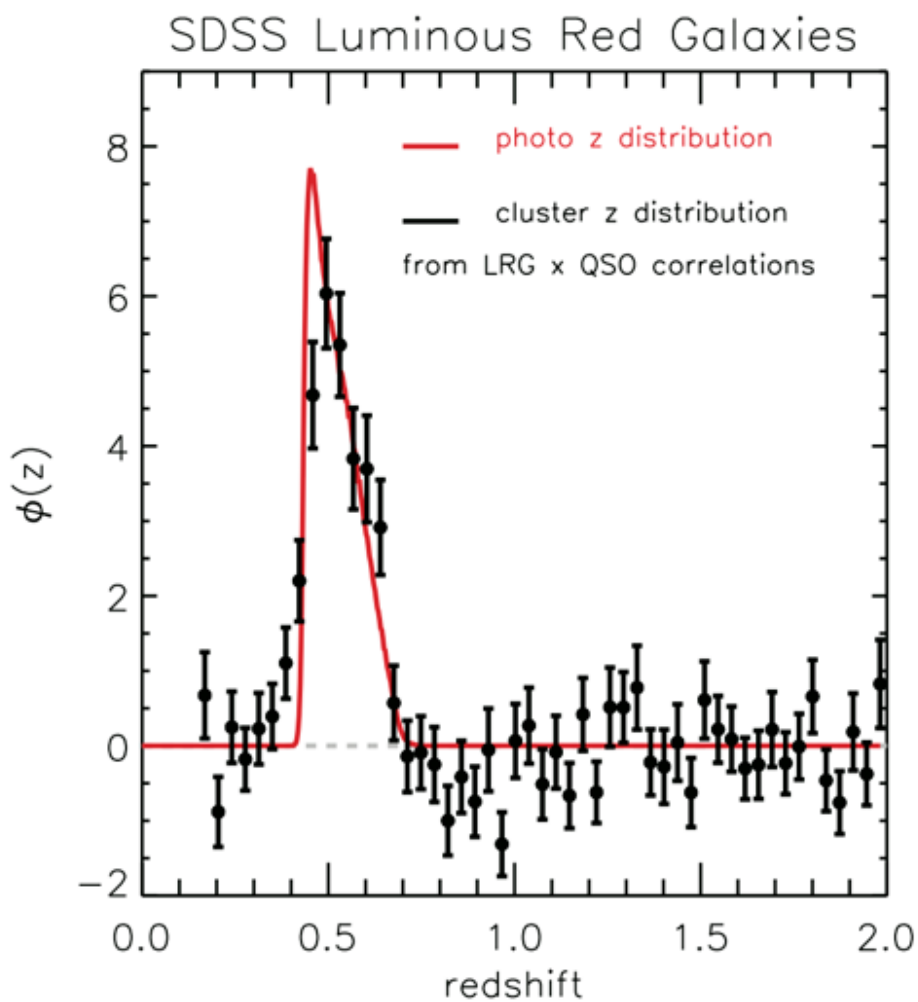
Ilbert et al. 2009

Higher-resolution information can be obtained by cross-correlating with spectroscopic samples

- **Key advantage: spectroscopic sample can be systematically incomplete and include only bright galaxies!**
- **See: Newman 2008, Matthews & Newman 2010, 2011**

Red: Photo-z distribution for LRGs in SDSS

Black: Cross-correlation reconstruction using only SDSS QSOs (rare at low z!)



Menard et al. 2013

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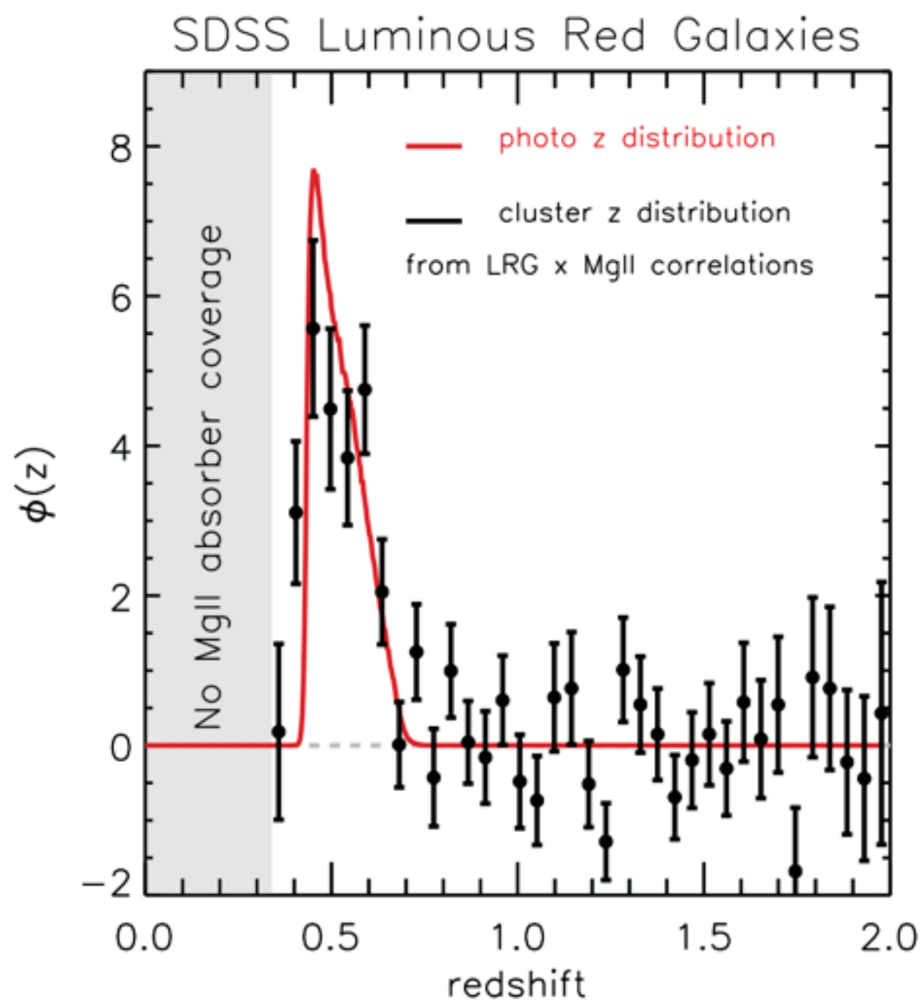
Red: Photo-z distribution for LRGs in SDSS

Black: Cross-correlation reconstruction using only SDSS Mg II absorbers (even rarer!)



Menard et al. 2013